Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Technical Standards for Determining	)	ET Docket No. 00-90
Eligibility for Satellite-Delivered	)	
Network Signals Pursuant to the	)	
Satellite Home Viewer Improvement Act	)	

To: The Commission

COMMENTS OF THE SATELLITE BROADCASTING AND COMMUNICATIONS ASSOCIATION

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SUMMARY

Currently, millions of American consumers who cannot receive a viewable television picture over the air are denied access to network programming via satellite. Therefore, SBCA urges the Commission to recommend modifications to the Grade B signal strength values and planning factor values in its Rules so that those values will reflect whether a household can actually receive an "acceptable" picture in today's highly complex signal propagation environment. As a result of technological developments, the current Grade B signal strength standard and planning factor values and other underlying assumptions upon which the current standard is based have become obsolete. In the Commission's 1998 rulemaking proceeding regarding the Satellite Home Viewer Act,[1] SBCA submitted, with its initial comments, an Engineering Statement prepared by Hatfield & Dawson in support of SBCA's recommendation that the Commission adopt certain revised Grade B signal strength values and planning factor values.[2] SBCA has reexamined these materials in light of the instant proceeding and has determined that not only do the analysis and conclusions in the Engineering Statement remain current and technically valid, they indicate the need for action by the Commission. Based upon Hatfield & Dawson's analysis, SBCA and its members urge the Commission to recommend to Congress the revised Grade B signal strength values and planning factor values discussed below, which will reflect more accurately the current signal propagation environment, consumer expectations regarding the acceptability of television transmissions via current analog technology, and heightened consumer expectations regarding transmission of high definition

[1] *See Satellite Delivery of Network Signals to Unserved Households for Purposes of the Satellite Home Viewer Act*, Notice of Proposed Rulemaking, CS Docket No. 98-201, RM No. 9335, RM No. 9345, FCC 98-302 (Nov. 17, 1998).

[2] *See* Hatfield & Dawson, *Engineering Statement: Technical Issues and Definitions Relative to the Satellite Home Viewer Act*, at n.2 (Dec. 1998) ("Engineering Statement"), attached hereto. The Engineering Statement was originally submitted to the Commission in CS Docket No. 98-201. *See* note 1 *infra.*

signals. By doing so, the Commission will both foster competition between the cable and satellite industries and further Congress' objective in adopting the SHVIA to facilitate the ability of satellite operators to retransmit network signals to those consumers who cannot receive such signals over-the-air.

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The Satellite Broadcasting and Communications Association ("SBCA") hereby submits its Comments in response to the Notice of Inquiry released by the Commission on May 26, 2000 in the above-referenced proceeding ("NOI").[1] The FCC issued the NOI to obtain information to allow it to evaluate whether the Grade B signal strength standard used to determine the eligibility of satellite television subscribers to receive retransmitted distant signals of network stations should be modified or replaced as directed by the Satellite Home Viewer Improvement Act ("SHVIA").[2] SBCA welcomes the opportunity to assist the Commission in recommending to Congress a standard that will best promote the public interest in ensuring the reception by consumers of network signals via satellite consistent with the SHVIA.

[1] *Technical Standards for Determining Eligibility for Satellite-Delivered Network Signals Pursuant to the Satellite Home Viewer Act*, Notice of Inquiry, ET Docket No. 00-90, FCC 00-184 (May 26, 2000).

[2] Although the SHVIA refers to an over-the-air signal of Grade B "intensity," *see* 17 U.S.C. § 119(d)(10)(A), we refer herein to signal "strength" rather than signal "intensity." As explained in the Engineering Statement, signal "strength" is the more technically accurate term. *See* Engineering Statement at 1 n.1.

I. THE COMMISSION SHOULD UPDATE THE GRADE B SIGNAL STRENGTH VALUES FOR PURPOSES OF THE SHVIA

Currently, millions of American consumers who cannot receive a viewable television picture over the air are denied access to network programming via satellite. Therefore, the Commission should include in its report to Congress a finding that the Grade B signal strength and planning factor values should be revised as proposed herein. Such modifications of the standard will best promote the interests of the public by allowing consumers who cannot actually receive acceptable over-the-air network signals to obtain such signals via satellite, which will in turn promote competition in the multichannel video programming distribution market.

The Grade B signal strength values set forth in Section 73.683 of the Commission's Rules, 47 C.F.R. § 73.684, which were adopted in 1952, were based upon planning standards and assumptions about the signal propagation environment that are generally acknowledged to be woefully outdated and no longer valid. For example, the planning standards were never adjusted to conform to the new propagation curves adopted in the 1970s.[3] In his 1977 report on television technical standards, FCC engineer Gary Kalagian noted that, "[w]ith the adoption of the new propagation curves, new values of R(T=10) should be used to calculate the time fading factors in tables 3A and 3B."[4]

In his report, Mr. Kalagian also questioned the validity of the assumption used in determining the Grade B signal strength values that there is no noise to overcome in so-called "rural" areas. He stated that, due to large population shifts, these areas are no longer rural and "[t]he assumption of 0 db to overcome rural noise in these 'rural areas' is probably no longer

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[3] Engineering Statement at 4.

[4] Gary S. Kalagian, Federal Communications Commission, *A Review of the Technical Planning Factors For VHF Television Service,* at 7 (1977).

valid because of the increased number of high voltage power lines and motor vehicle traffic volume."[5]

The Grade B signal strength values should be updated to accurately reflect a household's ability to receive an "acceptable" signal in today's more complex signal propagation environment. Based upon its analysis, SBCA and its member companies urge the Commission to recommend revised Grade B signal strength values of 70.75 dBu for low-band VHF stations, 76.5 dBu for high-band VHF stations, and 92.75 dBu for UHF stations. These values represent, in each case, the highest in a range of values for low-band VHF stations, high-band VHF stations and UHF stations set forth in the Engineering Statement.[6] The application of the highest values is amply justified by the official source materials cited therein. Indeed, the highest values in the ranges are conservative because they have not been adjusted to account for man-made noise, ghosting and continually increasing consumer expectations concerning acceptable picture quality.

These recommended Grade B signal strength values have been derived from the same planning factors currently set forth in the Rules, with modified planning factor values (taken directly from previous Commission staff reports, Commission findings and other official sources) that are more appropriate than those now in force.[7] The planning factors for the current Grade B standard were developed in the early 1950s. Circumstances and assumptions have changed dramatically since then, but the planning factors have not been updated. As explained in the Engineering Statement, the values for receiver noise figure, required signal-to-noise ratio, receiver antenna gain, line loss, and delta T are no longer valid.[8] They should be modified to the

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5 *Id.* at 11.

6 *See* Engineering Statement at Appendix 2.

7 *Id.*

8 *See id.* at 2-5 and Appendix 2.

values set forth in Appendix 2 to the Engineering Statement in order to accurately reflect whether a household can receive an "acceptable" picture today.

Specifically, SBCA proposes increasing the signal-to-noise ratio. The original value assumed zero noise in rural areas. Even in 1977, however, as Mr. Kalagian noted in his report, much of what was rural in 1952 had become suburban or even urban, with the attendant increase in man-made noise. This change in the viewing environment, which has continued and indeed has accelerated since 1977, has a direct impact on reception of TV signals. Accordingly, the signal-to-noise ratio must be increased for the Grade B signal strength value to accurately account for the effects of man-made noise on signal reception.

SBCA also proposes to adjust the receiver antenna gain figure. The original figure, again developed in the early 1950s, was based upon the assumption that viewers would install separate antennas for each television channel that they wanted to receive. Virtually all markets now have a combination of VHF and UHF stations, however, and if a consumer installs a rooftop antenna at all, it will most certainly be an all-band antenna, which reduces the gain. The figures proposed by SBCA are taken from the Commission's UHF Comparability Report and an NTIA Report on band antennas.[9]

In addition, SBCA recommends revised values for the line loss planning factors.[10] As with the other planning factors, the line loss values in the current Grade B standard were developed many years ago based on assumptions about antenna systems that are no longer valid. For example, as the Commission noted in the NOI, the original line loss planning factor was based on the use of 300-ohm twin lead cabling. However, most antenna systems today use 75-

[9] *See* UHF Comparability Task Force, Office of Plans and Policy, Federal Communications Commission, *Staff Report on Comparability for UHF Television, A Preliminary Analysis,* at Table B-1 (Sept. 1979) ("UHF Comparability Report"); Engineering Statement at Appendix 2.

[10] *See* Engineering Statement at Appendix 2.

ohm coaxial cable.[11] While these systems are more immune to electrical noise and RF interference pick-up, their signals attenuate more than signals carried over twin lead of the same length.[12] Moreover, as Mr. Kalagian noted in his 1977 study, the manufacturer specifications on which the original line loss values were based assumed new, dry cable. To arrive at his recommended revision of the line loss value, Mr. Kalagian averaged the values for new, dry cable and old, wet cable. A purpose of the SHVIA is to ensure that unserved households can receive network signals via satellite, it is essential that the line loss value be based on real world conditions, such as the type of cabling used and the effects of age and environmental conditions. The Engineering Statement properly takes these factors into account. SBCA's revised line loss values are taken from the Commission's UHF Comparability Report, with an additional loss calculated for a "splitter" device that lets two TV sets share a common antenna. The added splitter loss is necessary to account for the average of two television sets per household.[13] When the Commission's existing standard was developed, the average household typically had only one television set.[14]

SBCA also recommends an increase in the "delta T" correction factor so that it is appropriate for use with current coverage prediction curves.[15] For analog TV, coverage computations are based on geographic points inside the Grade B contour where the field strength predictions for 50% of locations, and 50% time reliability (i.e., F(50,50)) are compared to the appropriate Grade B field strengths defined in Section 73.683 of the rules. However, an acceptable signal is actually based on a 90% time-reliable field strength (i.e., F(50,90)).

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[11] NOI at ¶ 16.

[12] *Id.*

[13] *See Cable Television Technical and Operational Requirements; Review of the Technical and Operational Requirements of Part 76 , Cable Television*, 7 FCC Rcd 2021, 2025 (1992) ("*Cable Report*").

[14] *See id.*

Therefore the Commission must use a "delta T" correction factor to extrapolate the F(50,90) field-strength values from the F(50,50) coverage prediction curves found in Section 73.699. The SBCA's recommended revised delta T correction factors are appropriate for use with the current coverage prediction curves that were adopted in the 1970s. The necessity of this revised 90% correction is described in the two UHF Comparability reports, and is derived from FCC/OCE RS77-01, *A Review of the Technical Planning Factors for VHF Television Service* by Gary Kalagian. The calculation follows the same method as the original derivation, but uses the newer propagation curves to derive the value.

These realities degrade picture quality, and SBCA's revised planning factor values adjust for these realities based entirely upon published reports and recommendations of the FCC and the National Telecommunications and Information Administration. Importantly, where changes have occurred that *improve* picture quality, SBCA has taken these changes into account and recommended *downward* adjustments in the planning factors. For example, SBCA recommends a reduction for the receiver noise figure, because improvements in receiver technology have reduced noise at the receiver inputs. The reduced receiver noise figure are taken from the Commission's UHF Comparability Report.[16]

The Commission has inquired as to whether it is possible to integrate ghosting into the signal intensity standard.[17] In SBCA's view, the answer to that is an unqualified **yes**. The need for such an adjustment is not seriously disputed – anything short of reflecting ghosting would fail to do justice to the millions of mainly urban consumers counted as "served" because they are predicted to receive a strong signal – though their picture may be hopelessly distorted by the multipath phenomenon.

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15 *See* Engineering Statement at 3-4 and Appendix 2.

16 *See* Engineering Statement at Appendix 2; UHF Comparability Report at Tables B-1 and B-2.

A methodology for implementing that adjustment is likewise available, and SBCA endorses the Comments of EchoStar Satellite Corporation on that issue filed concurrently herewith. In short, the main difficulty encountered in developing such a methodology has been that ghosting is not a function of reduced signal strength and, therefore, ghosting loss is not directly measured in dBu. This difficulty can be overcome by an equivalence rule between ghosting-related impairment and signal strength loss (based in turn on the correspondence of both ghosting and signal strength to the measurable level of picture quality degradation). Such an equivalence relationship has already been established.[18] Ghosting-related loss ranging from imperceptible to very annoying can be translated to grades on the ITU-R scale from 1 to 5. Signal strength loss can also be related to the same scale, establishing a correspondence between ghosting loss and signal strength loss and making it possible to incorporate ghosting in the signal intensity standard. As explained by EchoStar in its Comments, one way of implementing the equivalence rule is to simply subtract the dBu equivalent of the ghosting loss from the measured signal strength before determining whether the signal received satisfies the Grade B intensity standard.

For the foregoing reasons and as further explained in the Engineering Statement, SBCA urges the Commission to recommend modification of the planning factor values in Section 73.83(a) of the Rules, 47 C.F.R. § 73.83(a), to reflect a household's ability to receive an acceptable signal in the current technological environment.

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[17] NOI at ¶¶ 25-27.

[18] *See, e.g.*, J.W. Allnat and J.D. Prosser, *Subjective Quality of Television Pictures Impaired by Long Delayed Echoes*, IEEE Proceedings, 112, No. 3, at 487-92 (1965). See also L.E. Weaver, *The Quality Rating of Color Television Pictures*, J. SMPTE. Vol. 77, at 610-12 (1968).

II. ALTHOUGH THE EXISTING STANDARDS FOR DIGITAL SIGNALS ARE OUTMODED, DEVELOPING A NEW STANDARD AT THIS TIME WOULD BE PREMATURE

The existing digital service area contours were developed to overlap as much as possible with the Grade B analog contours for such purposes as avoiding interference between towers. As the Commission notes in the NOI, the existing planning factors for digital television involve the same physical considerations which have been generally considered to influence the quality of reception of over-the-air transmissions of analog television pictures by home audiences.[19] In light of technological realities, however, the analog and digital standards should not be tied to one another in this manner. The focus, for purposes of a digital standard, should be on whether specific households are able to receive a digital signal. Unlike the infinite variations in picture quality encountered with an analog signal, with a digital signal, a particular household will receive one of two possible types of pictures: either a perfect digital picture or a blue screen. In light of this stark contrast, satellite television providers should be permitted to serve those households that receive only the blue screen from a digital signal.

Although the existing predictive digital standard is invalid for this purpose, SBCA recommends that the Commission refrain from attempting to develop new digital planning factors and contours at this time. The digital television industry is still in its developmental stages. Studies and negotiations within the industry regarding digital signal propagation and processes are ongoing. For example, industry members are working on ghosting issues in the digital context. The results of such work may inform the Commission's inquiry into the appropriate digital standard. At this time, SBCA believes that the industry is not prepared to recommend what the proper predictive factors should be for a workable eligibility standard for digital television. The television industry is still dependent on analog signals and likely will be

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[19] NOI at ¶ 30.

until digital conversion in nearly complete in 2006 or later. Moreover, the Commission may ultimately make significant revisions to the analog Grade B standard as a result of this proceeding. At the very least, the Commission should delay until the new analog standard has been formulated before beginning to evaluate and formulate the new digital standard.

III. A STUDY OF VIEWER EXPECTATIONS FOR PURPOSES OF INFORMING THE COMMISSION'S INQUIRY REGARDING THE GRADE B SIGNAL STANDARD IS NOT AVAILABLE AT THIS TIME

As the Commission noted, a number of commenters observed that viewer expectations of what constitutes an acceptable television picture have increased dramatically since the Grade B standard was adopted.[20] However, the Commission also noted the absence of current studies documenting this change in viewer expectations.[21] SBCA agrees with the Commission that an updated, scientifically valid study on viewer expectations of acceptable television picture quality may be warranted and that at present, no such study exists.[22] At this time, SBCA is not able to advise the Commission on how changes in viewer expectations should be accounted for in revising the Grade B signal standard or its underlying factors for purposes of SHVIA.

CONCLUSION

For the reasons set forth above, the Commission should recommend to Congress, for purposes of the SHVIA, the updated Grade B signal strength values and planning factor values proposed herein. At this time, the Commission should refrain from evaluating the eligibility standard for digital signals.

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20 *Id.* at ¶ 14.

21 *Id.*

22 SBCA notes, however, that the Commission itself observed in 1992 that "a significant number of television sets in use are now 26 inches or larger diagonally, and black and white sets are uncommon. Notably signal degradation is more noticeable on larger and on color sets." *Cable Report* at ¶ 25.

Respectfully submitted,

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ENGINEERING STATEMENT

Technical Issues and Definitions Relative to The Satellite Home Viewer Act

In Response to
Notice of Proposed Rulemaking
In the Matter of Satellite Delivery of Network Signals to Unserved Households for Purposes of the Satellite Home Viewer Act
CS Docket No. 98-201

Prepared for
Satellite Broadcasting and Communications Association

12/98

Technical Issues and Definitions Relative to the Satellite Home Viewer Act

The Satellite Home Viewers Act describes a distinction between served and unserved households to allow determination of eligibility for direct satellite provided network television service. In order to perform the test described by the Act, however, specific procedures and definitions must be established. The Federal Communications Commission has recognized this fact in promulgating a Notice of Proposed Rulemaking to resolve these issues. The technical matters which the Commission proposes to review are the definition of Grade B signal, and the selection of a methodology for accurately determining the eligibility of an individual household.

To provide a basis for definition of a Grade B field strength for a given household, the statistical factors inherent in propagation analysis are reviewed. From previous FCC and NTIA sources, modified planning factors are identified. The shortcomings of the Longley-Rice 1.2.2 model are described and use of the Terrain Integrated Rough Earth Model ("TIREM") is recommended. The use of additional losses due to foliage and to land use clutter, based on USGS data, and interference computations similar to those in the DTV planning process are recommended. Recommendations for measurement procedures equivalent to a "conventional outdoor rooftop receiving antenna" are described.

1. Signal Levels vs. Service Contours

The Satellite Home Viewer Act ("SHVA") refers to an "over-the-air signal of Grade B intensity." Unfortunately, the most common use in broadcast engineering of a signal (strength) of grade B magnitude is for the purpose of defining the Grade B contour of television station service.[1]

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[1]The SHVA uses the term "signal (of grade B) intensity," which is incorrect. The FCC Rules define television signal magnitudes in terms of field strength. The two terms are essentially synonyms in normal English use, but have distinct meanings as terms of art. Signal power is described as field intensity, generally measured in units and subunits of Watts/meter^2. Signal strength refers to electric and magnetic field values generally measured in Volts/meter or Amps/meter. These usages are described in The IEEE Standard Dictionary of Electrical and Electronics Terms, ANSI/IEEE Standard 100-1984. For the remainder of this discussion the correct terms signal strength and field strength will be used for consistency with FCC usage. Signal power density and field strength can, in normal radio propagation conditions, be converted one to the other using the impedance of free space, 120π,

It is understandable, therefore, that the two expressions sometimes become confused with one another. Simply stated, the Grade B contour of television station service is an area in which there may be, but there may also not be, an available signal strength of the level defined as a Grade B signal by the applicable Rules of the Federal Communications Commission. It is of utmost importance in the context of the SHVA to carefully define these terms and to distinguish between them.

The distinction is between:

- predictions of signal magnitude (the calculated signal strength or level at a given specific location, specified within certain probability limits), and
- service or signal contours (the locus of points where the probability of a signal of a given signal strength falls below a specified level).

In addition to the distinction between the physical meaning of these two terms, the statistical measures used to describe these two conditions are substantially different, as is noted below in Sec. 3.b.

The SHVA speaks to signal magnitude (signal strength or level) at specific household locations.

2. Definition (or re-definition) of the Grade B Signal Strength Level

The language of paragraphs 27 and 28 of the NPRM welcomes new evidence that would support proposals to make changes in the Grade B definition, when based on evidentiary showings. Such evidentiary information, in substantial quantities, appears in the Commission's own actions, and in its staff reports, over the last several decades.

What is Grade B signal strength? The grade B signal strength levels were established by the Commission based on calculations about the necessary signal to produce an acceptable picture to a specified percentage of viewer locations for a specified percentage of time. These assumptions are called planning factors. They include:

Thermal Noise of Ideal Receiver
Receiver Noise Figure
Necessary Signal to Noise Ratio
Dipole Factor
Antenna Gain
Line Loss
delta T (Statistical Correction 50% to 90%)

Additionally, a statistical factor for signal to noise ratio as it affects picture acceptability may be added to the FCC values, since the Commission assumed 30 dB, and the 90% acceptability value is known to be 34 dB. Ghosting is a significant factor in unsatisfactory signal recovery, but may be difficult to quantify with precision. Since more than 70% of U. S. households now have on average at least 2 television sets, a 3 dB splitter loss may also be appropriate. Since the SHVA does not mandate a specific height, use of the household roof height appears appropriate, although this does not actually enter into the planning factor computations, but is an input parameter for ambient signal level predictions and a protocol for measurements

It is important to note, however, that the Grade B definition contained in the rules is really a moving target and not a fixed value. For example (using the low band VHF case numerical values), the established level of signal for the production of the "just acceptable" picture is 41 dBu. This is the signal level that is the equivalent (translated from a signal in space to a voltage at the receiver terminals) of that which would be required from a steady state non-fading source (such as a VCR or a cable hookup) to just overcome thermal noise and receiver noise by the amount which is necessary to produce a TASO Grade 3 "passable" picture.

The Commission prefers to use calculations that are "median" (50% values) for all of its prediction techniques, probably because determination of median values of any random data is the most reliable statistical parameter. To obtain the 90% time for Grade A and Grade B service which the Commission has determined is appropriate for reliable service in a time-variable "fading" environment, characteristic of signal transmission through space, the planning factor equation weights the 41 dBu signal requirement by 6 dB for Grade B and 3 dB for Grade A. The difference between these two numbers reflects the fact that, for the average relatively unobstructed path, the terms for time variability converge as the distance to the transmitter decreases. This is intuitively obvious when one considers that the closer one is to the transmitter site, the smaller the amount of "uncertain" propagation included in the analysis unless the site is significantly obstructed. Unfortunately, these values, as chosen by the FCC, are somewhat arbitrary. They not only vary with distance from the transmitter site but also vary with the elevation of the transmitter site, although the FCC has chosen to use an arbitrary fixed height, and the 50% to 90% correction factors were not adjusted to conform to the new propagation curves adopted in the 1970's (see OCE R-6602). They also vary with the choice of the statistical fading model, although lognormal fading is generally assumed. Even if lognormal fading is the appropriate choice, the issue is further complicated by the necessity of choosing a standard deviation, which also affects the correction factors.

There is another matter that is glossed over in the selection of the planning factors that is variable in terms which can be related to percentages. O'Conner, relying on TASO data reported in H. Fine, FCC Rpt. TRR 5.1.2, points out that the selection of an acceptable signal to noise ratio is extremely subjective. For 90% of viewers to receive a "passable" (TASO Grade 3) picture the s/n. Is 34 dB, and for 50% it is 28 dB - a difference of 6 dB that matches nicely the 6 dB signal strength requirement to move from 50% to 90% time variability. In the Report & Order in MM Docket 91-169 and 85-38, the Commission specifies 36 dB.

The values selected for planning factors have been carried through to the present time from the early 1950's, the days of black and white television and limited national service, despite substantial evidence that these values are outmoded and in need of modification. The most significant FCC analysis of the matter is contained in the "UHF Comparability Study," prepared almost 20 years ago. There the Commission staff determined that 4 of the 7 planning factors for Grade B determination should be revised. The exceptions were the required signal to noise ratio, and the two factors that arise from physical principals that are not subject to adjustment, receiver noise level, and antenna dipole factor. And, as noted above, the one of these subject to empirical determination, required signal to noise ratio, should also be modified to provide actual 90% viewer acceptability.

The attached tables, drawn entirely from previous FCC analysis of appropriate parameters for determination of "acceptable" service, provide a range of traditional planning factor variables that are more appropriate than those now in force. In addition, the effect of other well-recognized propagation impairments, from government expert agency or other well-recognized semi-official sources, are also outlined.

3. Prediction Techniques

a. Choice of Method

The Commission states clearly in the NPRM that predictive techniques can "be effective proxies for individual measurements." Unfortunately, the discussion of the nature of predictive processes at paragraph 32 is fairly simplistic in its discussion of the statistical processes involved.

While it is true that the use of the Commission's median propagation curves, described in Sec. 2, above, leads to the use of a correction of the signal level to adjust probabilities, the discussion should make clear that the Commission's methods are very imprecise, and have not been corrected over the past 35 years, not even to match the propagation curves now in use, although the Commission was advised by its own staff to do just that, in RS77-01 and in the UHF Comparability Reports.

In the NPRM, the Commission suggests the use of the Longley-Rice model, particularly the ITS/ITM implementation version 1.2.2, used for DTV analysis. For a number of reasons, this is a far from ideal tool for the purposes implied by the SHVA. 1.2.2 is quite valid for the "area" implementations and general circumstances required for the DTV planning process, but other methods are more appropriate for point-to-point individual site determinations such as those required for SHVA purposes.

TIREM ("Terrain Integrated Rough Earth Model") is, like Longley-Rice, an implementation of concepts outlined in Tech. Note 101. It is designed for "tactical" use, that is, to be conservative about the analysis it performs. TIREM, like Longley-Rice

1.2.2, has a long history of use for broadcast signal prediction.

The most complete "one-stop" description of various radio propagation models and their most frequent implementations is contained in the section "Evaluation of Current Models," Section V of the Special Issue on Mobile Radio Propagation "Coverage Predictions for Mobile Radio Systems Operating in the 800/900 MHz Range," of the IEEE Transactions on Vehicular Technology, February 1988. This treatise outlines the genealogy of various propagation analysis methods, first describing the material contained in National Bureau of Standards Technical Note 101, the "workbook" upon which most, if not all, later analysis methods rely for much of their methodology. The VTS article states: *"Many of the specific ideas presented in Tech. Note 101 are utilized in other prediction methods. Most notably, the Longley-Rice computer method is a direct application of the Tech. Note 101 information. Also, various parts of TIREM are based on Tech. Note 101 concepts."*

The VTS article devotes approximately 8 pages to descriptions of the specifics of parameters used for input to the Longley-Rice programs, their calculation techniques, and later modifications of the program methods to broaden and improve their utility. The article also explains the differences between the "area" and "point to point" versions of Longley-Rice. This difference is important, and can be quite confusing, since with the advent of ubiquitous high capacity computers almost all area predictions are now carried out using the point-to-point version of Longley-Rice with very large numbers of individual calculations at multiple points along radials or at individual "tiles" (cells or grid locations) distributed evenly over the study area. Even further confusion is caused by the fact that the standard reference work on the later versions of Longley-Rice of both varieties is NTIA Report 82-100, misleadingly titled "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode". This report contains a very complete description of the statistics applicable to propagation calculation, which will be further discussed below.

The NPRM suggests, at paragraphs 34-5, the use of the Longley-Rice Version 1.2.2 model which was adopted for DTV purposes. The discussion does point out the satellite service providers' concerns about the absence of clutter, vegetation, and interference factors in this analysis. These are among the several factors which must be considered in the analysis in addition to basic transmission loss. Land use/land clutter factors (defined in four groups in recommendations of the Telecommunications Industry Council, frequently followed by the Commission) as well as interference factors, must be included. (The area within the F(50,50) defined grade B contour, the "traditional" measure of TV station service, is frequently interference limited.) The Commission does not, however, consider the computational shortcomings of the Longley-Rice 1.2.2 model, as were specifically outlined by many commenters requesting reconsideration of matters adopted in the Fifth and Sixth Reports and Orders in MM Docket 87-268, the DTV rulemaking.

As an example, in several of the Petitions for Reconsideration of matters adopted in the Fifth and Sixth Report & Order in MM Docket 87-268, television licensees outlined and, in some cases, marginally documented well-known problems with Longley-Rice, including the 1.2.2 implementation. In circumstances where the program's capabilities are exceeded, it cannot compute a result that falls within its "confidence" limits, and therefore returns an error code. The 1.2.2 version of the program assumes service (that is, signal above the desired threshold) for these conditions. It also does not compute interference for these conditions. This is really of trivial importance in the broad brush determinations appropriate for DTV allotment and service analysis. The results provided are manifestly more valid than the use of the simplistic F(50,50) and F(50,10) method of §73.684 et seq, and the Commission wisely chose to ignore reconsideration requests based on these grounds, and to continue on its intended procedure, use of the 1.2.2 method.

For the purposes of implementation of the SHVA, however, the circumstances are very different. In the DTV proceeding, the Commission was concerned with the general replication of service over wide areas. In the SHVA situation the Commission is compelled by the statutory language to provide a method which is valid for computation of service at individual household locations. Because it is manifestly just at those locations where propagation path impairments may result in input parameter variations which cannot properly be calculated by Longley-Rice 1.2.2, its use for SHVA compliance testing is unsupportable.

TIREM, mentioned above, is yet another implementation of concepts outlined in the Tech. Note 101 document. TIREM, like Longley-Rice, and like the Tech. Note 101 document, was developed by a Federal government agency, NTIA, in this instance acting for the DOD. TIREM can be described as "tactical" methodology, designed to be conservative about the analysis it peforms. The current version of the program is available from NTIS, accession #PB-97-501464, at a cost of $175, or can be downloaded from the NTIA website (http://ntiacsd.ntia.doc.gov/msam). And, like the other Tech. Note 101 methodologies, it has a long history of use for broadcast signal strength and coverage analysis. The Corporation for Public Broadcasting contracted with the DOD agency for which TIREM was created, the Electromagnetic Compatibility Analysis Center ("ECAC" now renamed "JCS") to use TIREM for the "AREAPOP" studies that it conducted for PBS television stations in the late 1970's. CPB also arranged to provide the service to many commercial FM and television stations on a task order basis, reasoning that the greater the amount of reliable coverage information that was available in the industry, the better. TIREM's conservative assumptions do not make it a particularly good tool for determining service contour or other generalized wide area coverage analysis studies, but it is a very useful program for testing specific paths, especially those with complex geometry. CPB's choice of the program was based on its ability to clearly show "islands" of poor coverage, and other quite topographically specific coverage anomalies well within the predicted Grade B contour of television stations. This, of course, is precisely the sort of propagation path which is likely to be the case for potential SHVS customers, those who cannot obtain good service from local television stations, despite location within the Grade B, or even the Principal community coverage contour.

b. Propagation Statistics - the Four Variables and their Meanings, and How they Affect the Four Modes, and other Manifestations of their Nature

Fundamental to all predictions of signal strength received after transmission by radio frequency waves through space are the factors that make such reception variable. Signals are variable with time, with location, with circumstance or situation, and with short-term or small displacement change.

The NTIA Report 82-100 "Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode" and, referring to it, the IEEE Transactions on Vehicular Technology "Coverage Predictions for Mobile Radio Systems..." contain explanations of the circumstances and relationships of four statistically variable parameters which are of fundamental importance in describing signal strengths. They are described as follows:

"Signal Variability Predictions: The original 1968 Longley-Rice Report (NBS Tech. Note 101) *and associated computer programs do not describe how to compute signal variabilities. Several subsequent publications have treated location variability. A 1976 OT Report* (OT Rep. dated May 1976) *develops equations for predicting location variability as a function of wavelength and the terrain irregularity parameter. A 1978 report* (OT 78-144) *compared location variability results based on the 1976 report with results reported by Okumura* (Rev. ECL v. 16, pp. 825 - 873, 1968) *and Egli* (Proc. IRE, v. 45, pp. 1383-1391, 1957) *and concluded that the 1976 equations predict 'more variability than that observed by Okumura in Japan" but agree "with the relationship shown by Egli in 1957." Finally, the 1982 report* (NTIA 82-100) *contains a detailed discussion on "Statistics and Variability" and also includes computer code (as part of the Longley-Rice model, version 1.2.1) that implements the procedures discussed. The report (p. 28) specifically excludes the "short-term or small displacement variability that is usually attributed to multipath propagation." Three basic types of variability are defined:*

1) time variability - variations of local hourly medians on a specific path with time;
2) location variability - variations in long-term statistics that occur from path to path;
3) situation variability - variations in location variability that occur from situation to situation.

The report and associated computer programs define four different variability modes for combining these three basic types of variability, namely:

1) single message mode - time, location, and situation variability are combined together to give a confidence level;
2) individual mode - reliability is given by time availability, while confidence is a

combination of location and situation variability;
3) mobile mode - reliability is a combination of time and location variability, and confidence is given by the situation variability;
4) broadcast mode - reliability is given by the two-fold statement of at least qt of the time in ql of the locations, with confidence given by the situation variability.

In addition, they provide an option whereby location variability is eliminated, as it should be when a well-engineered path is being treated in the point-to-point mode. A second option is also provided for eliminating situation variability, as it should be when considering interference problems."

This extensive discussion has been outlined in full because it points out the important differences between predictions (and measurements) for SHVS compliance, as defined in the Act, and all other broadcast predictions analyzed by, or performed for, or predicated on the basis of, or otherwise treated by the FCC in its capacity as the technical regulator for the broadcasting services. An even more complete description is provided by the underlying reference, Chapter 6, pp. 26-38 of NTIA Report 82-100. This chapter is included as an appendix.

For the individual path, specific location, "unserved household" case, the circumstances of definition (2) rather than definition (4) apply: time variability, which should be 90% to be consistent with all broadcast reliability definitions, and confidence variability, which, to apply to the specific location, should be as high as statistically meaningful, in the range of 90 or 95%, to correspond to the specific location.

c. The Use of Point-to-Point Techniques for SHVS Eligibility Testing

The use of specific point-to-point software implementations to screen consumer eligibility is not a difficult or expensive task for service providers. The street address of any household in the U.S. can be used to determine a set of geographic coordinates to the nearest second, using ubiquitous and inexpensive commercially available software. Software can be developed by users from Federal government sources for recent versions of TIREM and Longley-Rice. The FCC's television station database can be used to obtain data on the transmitting facilities of all television stations licensed by the FCC. Land use and land cover data, and topography data are available from the U.S. Geological Survey, and from other Federal sources. Given that there will be a modest number of potential customers for efficient and easy to use software, it's likely that commercial software vendors will package suitable offerings for that user community.

- Terrain: Unlike area/contour prediction methods, point -to-point prediction methods require detailed terrain information about the particular propagation path of interest. Both TIREM and Longley-Rice 1.2.2 require the highest-resolution terrain database available in order to provide accurate predictions of signal strength at a specific site - this is especially true if hills, ridges and other terrain features obstruct the radio path between the transmitter and receiver. Fortunately, the USGS has a publicly-available 3" (arc-second) resolution terrain database which we believe is sufficiently accurate for point-to-point propagation studies of terrestrial television signal strength conditions.

TIREM: Has the following advantages over Longley-Rice 1.2.2:

- i) Calculates losses due to terrain obstructions (i.e., diffractive losses) using a much more sophisticated technique which involves up to 9 different modes which are automatically selected by the program to suit the exact conditions along the propagation path.
- ii) Includes techniques to minimize or eliminate abrupt discontinuities in calculated loss along a path. These discontinuities are common in 1.2.2 calculations.
- iii) Can handle receiving sites which are close to obstructions without returning error messages like 1.2.2.
- iv) Continues to be refined by NTIA and others.

b. Land use data

The USGS offers to the public a LULC (Land Use and Land Clutter) database which can be used in conjunction with a modified TIREM program to determine additional losses due to foliage and other land use conditions which exist in the vicinity of the receiving location. A specific set of adjustment factors, using the

USGS definitions as a basis, has been recommended by TIA in its Draft "Recommended Methods for Technology-Independent Modeling, Simulation, and Verifications" (TSB-88B). This data includes the effects of both land use, that is, the type of man-made building structures and level and characteristics of urbanization and other artifacts, as well as those types of vegetation which can influence radio propagation.

c. Interference

As noted above, the service area of television stations under the allotment scheme in use in the U.S. is, in many cases, severely interference limited at the fringes of the defined Grade B contour. This means that individual receiver locations well within that contour, even in areas where the basic signal from the desired station is above the minimum threshold of acceptable performance, may not receive a satisfactory Grade B signal (as defined by the Commission's own allotment standards) because the interference level from other stations may degrade that signal below acceptable performance levels. A precise model of this interference is no easier to obtain than a precise model of desired signal, but it may be calculated using the same statistical assumptions as the desired signal but with lower time variability to reflect the Commission's definitions. Any analysis of Grade B signal level must include an analysis of this interference level. The Commission's DTV allocation methods include just such an analysis.

4. Measurements and Measurement Techniques

For accurate and valid measurements of received signal it must be understood that there are potentially significant variables in signal strength exhibited in measured data. There is both time variability and location variability, and to make things even more confusing, there is both short-term and long term variability or "fading." Short term variability can generally be ignored by averaging the measurement over a short period of time, or averaging a number of spot essentially instantaneous measurements.

Long term variability is a much more difficult problem, however, in the context of large numbers of measurements at large numbers of different, discrete locations, the effects of long term variability will average out over the group of measurements, even though individual measurements cannot be adjusted with only one-time measurement data.

Two measurement protocols will provide meaningful results. If a test antenna of known antenna factor is available, a measurement made adjacent to a residential structure at an elevation equivalent to the roof line or slightly above it will result in measured data that is comparable to "use of a conventional outdoor rooftop receiving antenna."

If the household has a "conventional outdoor rooftop receiving antenna" then the signal strength (in volts terminated in the characteristic impedance of the coaxial or twin-lead transmission line) can be made at the receiver terminals. This requires a bit of mathematical manipulation, but details of the requirements are provided in an appendix to this report.

As noted above, measurements should use a test antenna at roof level as close as possible to the residential structure, alternatively, a measurement of signal equivalent to the rooftop field strength measured at the antenna termination of the household. (This will be different for every channel and different for 75 ohm and 300 ohm terminations.)

The calculation of appropriate set terminal signal (dBm) should be performed using the same assumptions as suggested for revised planning factors, including antenna gain, cable loss, and splitter loss, or actual values if available.

The measurements should be made at thirty second intervals over a period of five minutes, for a total of 10 measurements. To show 90% time levels, if more than one of the 10 measurements is less than the Grade B value, the household shall be classified as unserved.

December 9, 1998

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APPENDICES

1. Bibliography
2. Recommended Planning Factors
3. Present FCC Planning Factors
4. Additional Service Impairment Attenuation Factors
5. Desired/Undesired Ratios for NTSC Interference Calculation
6. Section 6 "Statistics and Variability" from NTIA Report 82-100

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APPENDIX 2

Recommended Planning Factors

Low VHF/ High VHF/ UHF

Range of Values	low	Notes	high	Notes
Receiver Noise Level	7	1	7	1
Receiver Noise Figure	6/7/12	2	12/12/14	3,4
Required Signal to Noise Ratio	34 (or 36)	5	43	6
Dipole Factor	-3/6/16	7	-3/6/16	7
Receiver Antenna Gain	-3.5/-7.5/-9.25	8	-2.25/-6.5/-5.25	8,9
Line Loss	2/3/6	10	5/6/9	11
Δ T median to 90% Correction factor	9	12	9	12
Corrected Grade B Signal Strength	53.5/60.5/76.75		70.75/76.5/92.75	

1 Determined uniquely by bandwidth (4.2 MHz)
2 UHF Comparability Report Table B-2
3 UHF Compatibility Report Table B-1 (present values)
4 47CFR 15.117(9) for UHF
5 O'Connor quoting Fine, FCC Rpt. TRR 5.1.2, see also 7FCC Rcd 2021 Par 38 which calls for 36 dB
6 47CFR 73.605(a)(7) and 7FCC Rcd 2021 Par 37-39
7 Determined uniquely by frequency
8 Positive values are losses, negative values are gains - see Table B-1, UHF Comparability Report
9 NTIA Rep 79-22 for all band antennas
10 UHF Comparability Report Table B-2
11 Additional 3 dB to include 1 splitter, see 7FCCRcd 2021 Par 25
12 UHF Comparability Report Table B-2

(Values given to nearest 0.25 dB)

Table B-1

Present FCC Planning Factors for the Grade B Contour

	Low VHF	High VHF	UHF
receiver noise level[1]	7	7	7
receiver noise figure	12	12	15
required signal-to-noise ratio [2]	30	30	30
dipole factor	-3	6	16
receiver antenna gain[3]	-6	-6	-13
line loss	1	2	5
delta T (90%) [4]	6	5	4
	47 dBu	56 dBu	64 dBu

Source: O'Connor, (1968)

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1 This is the inherent thermal noise of an ideal receiver.

2 This is the signal-to-noise ratio required in the average television receiver to produce a passable television picture (TASO grade 3). See O'Connor (1968).

3 Since this is a table of losses, a gain appears as a negative number.

4 This factor modifies the FCC F(50,50) curves, that predict service 50% of the time, to F(50,90) curves, that predict service 90% of the time.

a. For Use in Calculation Methodology

For use in calculating land use/land cover[1]

Vegetation (forest)	2/5/7
Clutter residential	3/7/10
Clutter urban comm/indust	4/9/12
(Values in dB)	

Interference Factors

In the DTV 6th Report & Order, (MM Docket 87-268) at Appendix B the D/U ratios for NTSC/NTSC interference are shown. For SHVA analysis, the TIREM predicted desired signal should be calculated for 90% time variability, and the interfering signal calculated with 10% time variability, as for is appropriate for calculation of interference. The D/U values from the 6th Report & Order are included in the attached appendix.

Ghosting (and other multipath impairments)

Substantial progress has been made in the characterization of multipath propagation especially at VHF frequencies, as a result of the implementation of digital PCS and cellular telephone systems. There have also been discussions of the use of "3D" propagation path modeling software for characterization of multipath effects on the digital television signal. Unfortunately, as outlined in TIA TSB-88A, there has not been adequate information to establish numerical methods for such computations, although such an effort should be made as a part of further studies to establish realistic modern NTSC (and digital television) planning factors.[2]

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[1] TIA TSB-88A, table 7
Data obtainable per USGS LULC Database. See USGS Data Users Guide #4.

[2] TIA TSB-88A at p.70-72.

Additional Service Impairments, Cont'd

b. For measurements

Antenna gain	2.25/6.5/5.25[3]
Line loss including splitter	-5/-6/-9[3]

Thus, for 75 ohm receiver termination, the voltage measured for a median frequency (channel 4, 67.25 MHz) low VHF field strength of 62 dBu is:

$$\begin{aligned} Pr\ dBm &= EdB\mu - 20 \log F - 75.1 + 2.25 - 5 \\ &= -52.4\ dBm \\ &= 5.75 \times 10^{-6}\ mW \end{aligned}$$

$$\begin{aligned} E &= (P \times R)^{1/2} \\ &= 657\ \mu V \end{aligned}$$

And for 300 ohm receiver termination, this value is doubled.

NOTE THAT THIS COMPUTATION IS FREQUENCY DEPENDENT!

[3] Note that positive values are gains, negative values are losses, unlike planning factor table.

- Interference between VHF NTSC stations is deemed to exist when the D/U ratio falls below the threshold values of -3 dB, 28 dB and -13 dB respectively for lower adjacent, co-channel and upper adjacent channel relationships. For example, the most favorable ratio of the three, -13 dB, applies if the desired station is on channel 7 and the interference is on channel 8.

- Interference between UHF NTSC stations on co- and adjacent channels is determined by the same D/U ratios used for VHF, and the criteria used for taboo channel interference are presented below.

Taboo Channel Relationship	NTSC-NTSC D/U Ratio (dB)
-2	-26.0
-3	-33.0
-7	-30.0
-8	-32.0

Taboo Channel Relationship	NTSC-NTSC D/U Ratio (dB)
+2	-29.0
+3	-34.0
+4	-23.0
+7	-33.0
+8	-41.0
+14	-25.0
+15	-9.0

The NTSC-to-NTSC ratios used for interference evaluation were determined by expert observers at the Advanced TV Test Center during the tests of digital systems. All values are threshold-of-visibility (TOV) observations, except the co-channel value of 28 dB which is the precise offset value corresponding to impairment rating 3 according to the Advanced TV Evaluation Laboratory in Canada. No observations were made for channel differences of -5, -4 and +5, and no calculations were made for these taboos when evaluating NTSC-to-NTSC interference.

APPENDIX 6

NTIA REPORT 82-100

A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode

report series

U.S. DEPARTMENT OF COMMERCE • National Telecommunications and Information Administration

6. STATISTICS AND VARIABILITY

We come now to a discussion of how the ITS irregular terrain model treats the statistics of radio propagation. As we have mentioned before it seems undeniable that received signal levels are subject to a wide variety of random variations and that proper engineering must take these variations into account. Unfortunately, the problem is considerably more complicated than problems of simple random variables one encounters in elementary probability theory.

The principal trouble is that the population of observed signal levels is greatly stratified--i.e., not only do the results vary from observation to observation (as one would expect) but even the statistics vary. Now it is not surprising that this should be the case when one varies the fundamental system parameters of frequency, distance, and antenna heights; nor is it surprising when one varies the environment from, say, mountains in a continental interior to flat lands in a maritime climate, or from an urban area to a desert. But even when such obvious parameters and conditions are accounted for, there remain many subtle and important reasons why different sets of observations have different statistics.

Our problem here is analogous in many ways to that of taking public opinion polls. There results depend not only on the questions asked but also on many subtleties concerning how, where, and when the questions are asked. If one spends the working day telephoning people at their homes, then one obtains the opinions of those people who own telephones and answer them and who have remained at home that day. This procedure might still be a random sampling and might, indeed, provide acceptable results, if it were not for the fact that public opinion is, again, greatly stratified--i.e., that the opinions of one segment of the population can differ greatly from those of another.

In the case of radio propagation, it is the equipment and how, where, and when it is used that provides an added dimension of variability. Perhaps one or both terminals are vehicle mounted and constrained to streets and roads. Perhaps, instead, one antenna is likely to be mounted on a rooftop. Perhaps it is most probable that both antennas are well removed from trees, houses, and other obstacles; or perhaps it is likely that one of the antennas is close to such an obstacle or even inside a building, whether this be for convenience or because concealment is desirable. It may be that two regions of the world appear, even to the expert's eye, to offer the same set of impediments to radio propagation and yet the differences--whose effects we do not understand--may be important.

In any case, the way in which equipment is deployed has an often important and unpredictable effect on observed signal levels. We propose here to use the word <u>situation</u> to indicate a particular deployment, whether in actual use or simply imagined. In technical terms, a situation is a probability measure imposed on the collection of all possible or conceivable propagation paths and all possible or conceivable moments of time. (A good introduction to the theory of probability measures is given by Walpole and Myers, 1972, Ch. 1.) To choose a path and a time "at random" is therefore to choose them according to this probability measure. Insofar as we want to get below the level at which stratification is important, we would want to restrict a situation (that is, to restrict the set of paths and times where the imposed probability is non-zero) to include only paths with a common set of system parameters, lying within a single, homogeneous region of the world. This is a natural restriction except, perhaps, as it affects the distance between terminals. The distance is a parameter which is difficult to fix while still allowing a reasonable selection of paths.

If we are concerned with a single, well-defined communications link with fixed terminals, then the situation involved has only a single isolated path which is to be chosen with probability one. But the deployment of a land-mobile system in one single area would define a more dispersed situation. Note, moreover, that if the mobile units pass from an urban area to a suburban or rural area, then we would suppose they pass from one situation to another. If one sets out to make a set of measurements of received signal levels, then one will sample from what is, if the measurement program has been properly designed, a situation pre-defined by the program objectives. Often the measurements will be in support of what will become a system deployment. It is then always proper to ask whether the situation from which the data are taken corresponds accurately enough to the situation in which the system will operate.

Once again, all this fussiness would be unnecessary--and radio propagation engineering would long ago have become a finely honed tool--if it were not that the population of received signal levels is a stratified one. The system parameters, the environmental parameters, and the situation in which one is to operate are all important and each of them has some effect on the final statistics. The complexity of nature often forces us to empirical studies of these statistics; but the large number of dimensions involved makes this a difficult task.

6.1 The Three Dimensions of Variability

We turn now to a general discussion of the physical phenomenology involved. First, we should note that there is a very important part of the variability that we do not wish to include. This is the short-term or small displacement variability that is usually attributed to multipath propagation. Although it is probably the most dramatic manifestation of how signal levels vary, we exclude it for several reasons. For one, a proper description of multipath should include the intimate details of what is usually known as "channel characterization," a subject that is beyond our present interests. For another, the effects of multipath on a radio system depend very greatly on the system itself and the service it provides. Often a momentary fadeout will not be of particular concern to the user. When it is, the system will probably have been constructed to combat such effects. It will use redundant coding or diversity. Indeed, many measurement processes are designed so as to imitate a diversity system. On fixed paths, where one is treating the received signal level as a time series, it is common to record hourly medians--i.e., the median levels observed during successive hours (or some comparable time interval). We may liken the process to a time diversity system. If measurements are made with a mobile terminal, one often reports on selected mobile runs about 30 m in length. Then, again, one records the median levels for each run, thus simulating a space diversity system. Under the "frozen-in-space" hypothesis concerning atmospheric turbulence, one expects hourly medians and 30-m run medians to be about the same. (But the analogy becomes rather strained for multipath in urban areas.) To the two measurement schemes above, it would seem reasonable to add a third to correspond to frequency diversity. This would be a "wideband" measurement in which the average or median power over some segment of the spectrum were recorded. In any case, it is only the variation of these local medians that concerns us.

If one still finds it necessary to consider instantaneous values of cw signals, then the usual practice is simply to tack on an additional variability to those we shall describe here. Often, one assumes either that the signal is locally steady (in areas where there is no multipath) or that it is Rayleigh distributed (in areas with extreme multipath). Occasionally one will assume an intermediate case, using the Nakagami-Rice (see, e.g., Rice et al., 1967, Annex V) distributions or the Weibull distributions.

If we set out to measure statistics of local medians, the first step that occurs to us is to choose a particular fixed link and record measurements of hourly median received signal levels for 2 or 3 years. The resulting statistics will describe what we call the time variability on that one path. We could characterize these observations in terms of their mean and standard deviation; but, both because the distribution is asymmetric and not easily classified as belonging to any of the standard probability distributions, and because the practicing engineer seems to feel more comfortable with the alternative, we prefer to use the quantiles of the observations. These are the values not exceeded for given fractions of the time and are equivalent to a full description of the cumulative distribution function as described in the elementary texts on statistics. We would use such phrases as "On this path for 95% of the time the attenuation did not exceed 32.6 dB."

If we now turn our attention to a second path, we find to our dismay that things have changed. Not only are individual values different, as we would expect given the random nature of signal levels, but even the statistics have changed. We have a "path-to-path" variability caused by the fact that we have changed strata in the population of observable signal levels. Suppose, now, that we make a series of these long-term measurements, choosing sample paths from a single situation. In other words, we keep all system parameters constant, we restrict ourselves to a single area of the earth and keep environmental parameters as nearly constant as is reasonable, and we choose path terminals in a single, consistent way. We still find that the long-term time statistics change from path to path and the variation in these statistics we call location variability. Of course, if the situation we are concerned with has to do with a single, well-defined link, then it is improper to speak of different paths and hence improper to speak of location variability. But in the broadcast or mobile services, it is natural to consider such changes. The most obvious reason for the observed variability is the accompanying change in the profile of the terrain lying between the two terminals; although the outward--statistical, so to speak--aspects of the terrain may remain constant, the actual individual profiles, together with other, less obvious, environmental changes, will induce large changes in observed signal level statistics.

If we try to quantify location variability, we must talk of how time variability varies with path location. We have no recourse but to speak of the statistics of statistics. Clinging to the terminology of quantiles, we would speak of quantiles of quantiles and come up with some such phrase as "In this situation there will be 70% of the path locations where the attenuation does not exceed 32.6 dB for at least 95% of the time."

Finally, we must ask what effect there is when one changes from situation to situation. It should be no surprise to be told that the statistics we have so painfully collected following the outline above have changed. If we use like appearing situations--that is, if we change operations from one area to another very similar area or if we merely change the sampling scheme somewhat--then the observed changes in the location variability we call situation variability.

In other contexts this last variability is sometimes referred to as "prediction error," for we may have used measurements from the first situation to "predict" the observations from the second. We prefer here to treat the subject as a manifestation of random elements in nature, and hence as something to be described.

To make a quantitative description however, we must renew our discussion of the character of a "situation." We have defined a situation to be a restricted probability measure on the collection of all paths and times. But if we are to talk of changing situations--even to the point of choosing one "at random"--then we must assume that there is an underlying probability measure imposed by nature on the set of all possible or conceivable situations. And we must assume that at this level we have specified system parameters, environmental parameters, and deployment parameters in sufficient detail so that the variability that remains is no longer stratified--in other words, so that any sample taken from this restricted population will honestly represent that population. It is at this point that "hidden variables" enter--variables whose effects we do not understand or which we simply have not chosen to control. The values of these variables are at the whim of nature and differ between what would otherwise be identical situations. The effects of these differences produce the changes in observed statistics.

We are now at the third level of the statistical description, and evidently we must speak of quantiles of quantiles of quantiles. This produces the phrase, "In 90% of like situations there will be at least 70% of the locations where the attenuation will not exceed 32.6 dB for at least 95% of the time."

In general terms such quantiles would be represented as a function $A(q_T, q_L, q_S)$ of three fractions: q_T, the fraction of time; q_L, the fraction of locations; and q_S, the fraction of situations. The interpretation of this function follows the same pattern as given above: In q_S of like situations there will be at least q_L of the locations where the attenuation does not exceed $A(q_T, q_L, q_S)$ for at least q_T of the time. Note that the inequalities implied by the words "at least" and "exceeds" are important reminders that we are dealing here with cumulative distribution functions. Note, too, that the order in which the three fractions are considered is important. First, one chooses the situation, then the location, and finally the time.

We recall that if a proposition is true with probability q then it is false with probability 1-q. Working our way through all the inequalities involved, we may also say: In $1-q_S$ of like situations there will be at least $1-q_L$ of the locations where the attenuation does exceed $A(q_T, q_L, q_S)$ for at least $1-q_T$ of the time. This is the kind of phrase one uses when trying to avoid interference.

6.2 A Model of Variability

As complicated as it is, the three-fold description of quantiles does not completely specify the statistics. At the first level when we are considering time variability it is sufficient. But at the very next level we have failed to notice that we are trying to characterize an entire function of quantile versus fraction of time q_T. To do this completely, we would need to consider all finite sequences q_{T1}, q_{T2}, ... of fractions of time and to examine the resulting observed quantiles all at once as a multivariate probability distribution. At the third and final level, matters become even worse.

Obviously this becomes too complicated for practical applications; nor would a study following such lines be warranted by our present knowledge. But there are engineering problems that arise which can be aided by a more complete description of these statistics. Implicit within the ITS irregular terrain model is a second model which concerns variability and which can be used to provide such a description. It is a relatively simple model using a combination of simple random variables each of which depends on only one of the three different dimensions of variability. While retaining the features described in the previous paragraphs, it allows the engineer to derive formulas for many needed statistics.

Experience shows us that when signal levels are expressed in decibel notation the observed distributions tend to be normal or at least approximately normal. It is from this fact that inspiration for the model is largely derived. The broad statement of normality does, however, suffer from one important flaw which appears when we discuss signal levels that exceed free space values. Such signal levels are possible and are, indeed, observed; but their occurrence is rare and becomes increasingly more rare as one considers ever higher levels. The distributions we obtain must be truncated or heavily abbreviated at levels above free space.

As it happens, the terminology the ITS irregular terrain model uses to describe the magnitude of variability differs in a slight way from that used above. As in Rice et al. (1967, Annex V), the model considers the positive direction of a deviation as an increase of signal level rather than of attenuation or loss. There is, of course, no real significance to this convention, but the introduction of an extra minus sign does tend to confuse our subsequent arguments. For this one section, therefore, we shall adopt a different posture. Using lower-case letters to refer to random variables, we suppose that the object of concern is the signal level w which we measure in a decibel scale. We leave the precise definition of this signal level deliberately vague, since it is immaterial here whether we speak of power density, field strength, receiver power, or whatever. It would be related to the attenuation a by the formula

$$w = W_{fs} - a \tag{3}$$

where W_{fs}, which is not a random variable, is the signal level that would be obtained in free space.

The above change in convention requires a slight change in our definition of a quantile. To retain the same relations as are used in practice, we now say it is the value which <u>is</u> exceeded for the given fraction. For example, if w were a simple random variable, we would define the quantile W(q) as being the value which w exceeds with probability q. We should perhaps refer to this as a "complementary" quantile, but instead we shall merely depend on the context to determine the implied inequality. The rule to remember here is that we assume the attitude of trying to detect a wanted signal. It must be sufficiently large with a sufficiently high probability.

Our model of variability is a mathematical representation of how one is to view the received signal level as a random variable. First we assume the system parameters, the environmental parameters, and the deployment parameters have been fixed. From the set of all situations with these parameters, we choose at random a particular one s. Then using that situation (which is, remember, a probability measure) we choose at random a location ℓ and a time t. The triple (t,ℓ,s) forms our elementary event, and the corresponding received signal level $w(t,\ell,s)$ becomes a random variable. The model expresses this function of three variables in a more explicit and manageable way. We first define a tentative value of the signal level

$$w'(t,\ell,s) = W_0 + y_S(s) + \delta_L(s)\ y_L(\ell) + \delta_T(s)\ y_T(t) \quad , \tag{4}$$

where W_0 is the overall median signal level; y_S, y_L, y_T are three random variables called <u>deviations</u>; and δ_L, δ_T are another two random variables called <u>multipliers</u>. The three deviations are measured in decibels and their median values are 0 dB. The two multipliers are dimensionless, always positive, with medians equal to unity. We now come to the important assumption that the five random variables here are all mutually independent. This enables us to treat each of them separately and then to combine them using standard probability theory.

The final step in our model is to write

$$w(t,\ell,s) = M(w'(t,\ell,s)) \quad , \tag{5}$$

where M is a <u>modifying</u> function which corrects values greater than the free space value. For values of w' less than the free space value, we set $M(w')=w'$; but otherwise M puts an upper limit on values or at any rate reduces them considerably. As presently constituted, the ITS irregular terrain model cuts back the excess over free space by approximately a factor of 10. Thus, if W_{fs} is the free space value of received signal level, we have $M(w') \approx 0.9\ W_{fs} + 0.1\ w'$ when $w' > W_{fs}$.

The statistics of the three deviations and the two multipliers depend on the system parameters, the environmental parameters, and the deployment parameters. Except that the two multipliers must be positive, the five random variables are approximately normally distributed. The deviations have standard deviations on the order of 10 dB, while the multipliers have standard deviations equal to 0.3 or less. The actual values have been derived from empirical evidence and engineering judgment.

Using this model we can, for example, recover the three-dimensional quantiles discussed previously by following the prescribed procedure step by step. At the first step we would assume there is a fixed situation and a fixed location at which we observe the received signal level as a function of time. Now one very useful property of quantiles has to do with the composition of random variables with monotonically increasing functions. If, say, u is a random variable with quantiles $U(q)$ and if F is a monotonically increasing function, then, as one can easily show, the random variable $F(u)$ has the quantiles $F(U(q))$. Since $\delta_T(s)$ is positive, the right-hand side of (4) is a monotonically increasing function of y_T, and therefore the time variant quantiles are given by

$$W_1'(q_T,\ell,s) = W_o + y_S(s) + \delta_L(s)\ y_L(\ell) + \delta_T(s)\ Y_T(q_T) \quad , \tag{6}$$

where $Y_T(q_T)$ is the q_T quantile of y_T. At the next step we would have a fixed situation and a fixed time variant quantile, and we would look at (6) as a function of location alone. Again, if $Y_L(q_L)$ is the q_L quantile of y_L, we quickly find what is now a twofold quantile

$$W_2'(q_T,q_L,s) = W_o + y_S(s) + \delta_L(s)\ Y_L(q_L) + \delta_T(s)\ Y_T(q_T) \quad . \tag{7}$$

At the third step we must consider (7) as a random variable since the situation s is now to be chosen at random. But here we have a new problem. The right-hand side of (7) is the sum of a fixed number W_o and three mutually independent random variables. The statistics of W_2' must therefore be computed from the convolution of the corresponding three probability distributions. When this has been done, we would pick off the desired quantile and finally come upon the threefold expression $W'(q_T,q_L,q_S)$. In the last step, we recall that the modifying function M is monotonically increasing and so

$$W(q_T,q_L,q_S) = M(W'(q_T,q_L,q_S)) \quad . \tag{8}$$

The only difficult part in this sequence of computations appears when we must find the convolution required by (7). To do this the ITS irregular terrain model uses an approximation sometimes called <u>pseudo-convolution</u>. This is a scheme described by Rice et al. (1967) to treat several applications problems where the sum of independent random variables is concerned. For completeness and because it is useful in many applications of the model, we pause here to provide our own description.

In the general case we would have two independent random variables u and v with corresponding quantiles $U(q)$, $V(q)$. We then seek the quantiles $W(q)$ of the sum $w=u+v$. We first form the deviations from the medians which we recognize as having quantiles

$$Y_U(q) = U(q) - U(0.5) \tag{9}$$

$$Y_V(q) = V(q) - V(0.5) \quad ,$$

and then we simply use a root-sum-square to derive

$$W(q) \approx U(0.5) + V(0.5) + \text{sign}(0.5-q)\ [Y_U(q)^2 + Y_V(q)^2]^{\frac{1}{2}} \quad . \tag{10}$$

If u and v are normally distributed, this expression is exact. For other distributions we can only say that results are reasonable and that in our own experience using distributions that arise naturally in the applications the expression is surprisingly accurate. It is, however, meant to be only an approximation and must always be treated as such.

Note that the extension of (10) to more than two summands is straightforward. The expression even shares with actual convolution the property of being associative and commutative so that the order in which summands are combined is immaterial.

6.3 Reliability and Confidence

The use of the three-dimensional quantiles is perhaps best illustrated by its application to the broadcast services. A broadcaster will need to provide an adequate service to an adequate fraction of the locations at some given range. But "adequate service" in turn implies an adequate signal level for an adequate fraction of the time. For television channels 7 to 13, for example, in order to provide Grade A service the broadcaster must deliver (O'Connor, 1968) a field strength 9 m above the ground which exceedes 64 dBμ for more than 90% of the time, and that in at least 70% of the locations. Spectrum managers and also the broadcast industry will in turn want to assure that a sufficient fraction of the broadcasters can meet their objectives. If we assume that each broadcaster operates in a separate "situation," then this last fraction is simply a quantile of the situation variability.

For other services, however, it is often difficult to see how the three-dimensional quantiles fit in, and indeed it is probably the case that they do not. Consider again the broadcast service. A single broadcaster will want to know the probability with which a given service range will be attained or exceeded. Since "service range" involves specified quantiles of location and time, the probability sought concerns situation variability and we return to three-dimensional statistics

On the other hand, consider the same problem from the point of view of an individual receiver. That individual will want to know only the probability at that one location of receiving adequate service--that is, of receiving an adequate signal level for an adequate fraction of the time. The distinction between location variability and situation variability will be of no concern and should not enter into our considerations.

Using our model as in (4) and (5) we quickly note how we can accommodate a new kind of analysis. We can suppose that first both the situation and the location are chosen simultaneously and then, second, the time. The first choice will have said that all four random variables in (4), excepting only y_T, are to be treated at once and are to be combined into a single deviation $y_S + \delta_L y_L$ and a single multiplier δ_T. What we would have remaining is a twofold description of variability involving time variability and a combined situation/location variability, and this is precisely the description that the individual receiver of a broadcast station would find useful.

To continue our discussions, we find it convenient here to introduce the term reliability. This is a quantile of that part of the variability which enters into the notion of "adequate service." For the individual receiver of a broadcast station, reliability is concerned with a fraction of time. For a broadcaster, however, reliability must be expressed as a twofold quantile involving time and location variability separately. For the remaining variability--always at a higher level in the hierarchy--we use the term confidence; and we mean this term in the sense that if one makes a large number of engineering decisions based on calculations that use the same confidence level, then, irrespective of what systems or even what types of systems are involved, that same fraction of the decisions should be correct--and, of course, the remainder should be incorrect. Reliability is a measure of the variability that a radio system will observe during the course of its deployment. Confidence will be measureable only in the aggregate of a large number of radio systems. Clearly, differentiation between the two will depend on the point of view one takes. To a broadcaster, confidence will be a measure of the situation variability; to an individual receiver of a broadcast station, it will be a measure of a combined situation and location variability. But the spectrum planner of the broadcast service will not speak of confidence at all; from that point of view all of the variability is observable and is part of the system.

Remembering that we must retain the order in which the three kinds of variability appear, there are four different ways that one can treat them in combination, all of which have legitimate uses in one kind of service or another. We call these the four modes of variability, although they are really four different ways of treating the subject of variability.

Two of these four modes we have already discussed. In the broadcast mode we treat all three kinds of variability separately. The typical user of this mode would be the broadcaster for whom reliability would measure both location and time variability and confidence would measure situation variability. In the individual mode situation and location variability are combined so that there remain this combined variability and time variability. Here, the typical user would be the individual receiver of a broadcast station for whom reliability means the time availability, and confidence measures the combined situation/location variability.

It would also be legitimate to combine location and time variability. We call the result the mobile mode, since to a mobile radio unit changes in location translate into changes in time. The typical user of this mode would be a mobile system employing a single base station. Reliability would refer to the combined location/time variability; it would probably translate into fraction of attempts at establishing communications. Confidence would be a measure of the situation variability.

Finally, in the single message mode we combine at once all three of the kinds of variability, thus obtaining the more usual sort of one-dimensional random variable. The statistics to be used here are much simpler than those we have been discussing; but, we think, the useful applications are somewhat limited. One application might be for a communications link that will be used but once. Examples might include a disaster warning system or a radio link attached to a self-destructing device. The statistics involved would then be couched in terms of confidence levels. A more important application, however, would be for a mobile-to-mobile system where the two mobile units are to be deployed worldwide. The statistics would translate into first-try success probabilities (Hagn, 1980) and thereby become expressions of reliability.

6.4 Second Order Statistics

Until now we have been discussing only first order statistics--that is, the statistics of received signal levels for a single path at a single time. But there are many problems in which more needs to be known. These are problems that depend on the relative signal levels on separate paths or at separate times. For example, the problem of interference comes first to mind. Also, there is the question of what happens on successive hops in a chain of communication links, or how to treat the connectivity of a network of repeaters such as has been suggested for military use.

The resolution of such problems depends on second or higher order statistics where one considers the joint probabilities of obtaining given signal levels over two or more paths. The most common statistic employed here is the correlation coefficient, but in the general case one might well be forced to use something more complicated.

Unfortunately, almost nothing is known about the subject. There have been studies concerning diversity systems in which correlation coefficients have been found for the two time series obtained when two receiving antennas are separated by only a few wavelengths or in frequency by only a small fraction of the carrier. But when it is a matter of the local median levels, studies of their possible relationships have been rare and inconclusive.

In attacking problems where higher order statistics are required, we seem forced to devise <u>ad hoc</u> approaches. In our own work on interference, for example, we have said that time and location variabilities are independent while situation variabilities are completely dependent. In other words, we have returned to the model in (4) and (5) and supposed two sets of these equations--one for the desired link and one for the undesired link. Thus we find a grand total of ten random variables to consider. Now in each set of five we have assumed these to be mutually independent; but one can still ask about correlations between terms of opposite equations. Our assumption, based on very meager information, has been that terms involving time and terms involving location are again mutually independent. On the other hand, we have argued that the situation involving the receiver is the same, or approximately the same, whether one considers the desired or the undesired transmitter. It would then follow, for example, that the two values of y_S are equal and therefore simply cancel out when one computes the desired-to-undesired signal ratio. Clearly, these assumptions must be viewed suspiciously; they enjoy only the benefit that they appear to give reasonable looking results.